Observing with SIRTF: Opportunities for the Scientific Community

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# of MS pages: 16 (includes space for figures and table)
# of figures: 4
# of tables: 1

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Abstract

The Space InfraRed Telescope Facility (SIRTF) is the fourth and final element in NASA's family of orbiting "Great Observatories." SIRTF consists of a 0.85-meter diameter telescope and three cryogenically-cooled science instruments capable of observing from the near- to the far-infrared, between 3 and 180 μm. Incorporating the latest in large-format infrared detector arrays, SIRTF offers orders-of-magnitude improvements in capability over existing facilities. Launch is scheduled for December 2001, with an anticipated lifetime of up to 5 years. SIRTF will observe targets ranging from small, icy bodies in the outer Solar System to the most luminous known objects in the distant reaches of the Universe. SIRTF represents an important scientific and technical bridge to NASA's new Origins program, and is managed for NASA by the Jet Propulsion Laboratory, California Institute of Technology.

1 Mission Overview

The Space Infrared Telescope Facility is the final element in NASA's suite of Great Observatories, and a scientific and technical bridge to NASAs ambitious new Origins program. SIRTF's technical capabilities, in combination with the compelling scientific basis for studying the Universe at infrared wavelengths, virtually assures that its legacy will favorably compare with those of the *Hubble Space Telescope*, the *Compton Gamma- Ray Observatory*, and the *Chandra X-ray Observatory*.

The political ramifications of an increased interest by the US electorate into expanding federal budget deficits in the early 1990s forced the original $2.2 billion version of SIRTF (as measured by development costs) to be rescoped twice to its current $0.45 billion cost. But as an illustrative example of the impact that ingenious engineering can have on scientific capability, one would be hard pressed to find an example whose benefits will exceed those from SIRTF. In particular, two engineering concepts being implemented with SIRTF serve to maintain most of the scientific vitality and potential of the original mission, despite an 80 percent reduction in development cost.

Unlike most flight development programs where the design and requirements are first completed, and then the contractors brought in to bid on development, the SIRTF Project embarked on an experimental approach. The Project Team members, including the industrial contractors, were solicited early enough to enable full participation in the preliminary design process. While JPL remains responsible for Project management, systems/mission engineering, science management, and flight operations, the other Team members have been actively working together during SIRTF's design phase. Lockheed- Martin (Sunnyvale, California, USA) is responsible for the spacecraft and for the system integration and testing. Ball Aerospace (Boulder, Colorado, USA) is responsible for the cryogenic telescope assembly. The SIRTF Science Center (SSC) is responsible for all aspects of science operations, and is located on the campus of the California Institute of Technology in Pasadena, California, USA.

Interested readers are urged to periodically visit the SIRTF Internet/WWW site *(http://sirtf.caltech.edu)* for ongoing developments.

1.1 The Orbit and Viewing Constraints

SIRTF will be launched in December 2001 into an Earth trailing heliocentric orbit, drifting away from Earth at a rate slightly higher than .1 AU a year and will have drifted to around .64 AU in 5 years. This orbit is favorable for both mass and thermal reasons and has helped reduce the development cost of SIRTF. In addition it provides advantages such as elimination of all occultations and eclipses providing continuous sky access and excellent visibility, considerably simplifying operations and augmenting observing efficiency. Now only the sun avoidance zone and the power-constrained zone drive SIRTF's main geometric observing constraints. (Figure 1) The operational pointing zone (OPZ) provides coverage over 35% of the sky. This allows each target to be visible for at least 40 days every six months if the target is near the ecliptic. The visibility increases to 60 days at an ecliptic latitude greater then 30°, up to 7 months of visibility at a latitude of 60°and constant visibility near the ecliptic pole. The enforcement of the OPZ keeps sunlight from striking any cold surface of the telescope and assures that the solar arrays powering the observatory remain well illuminated.

The only slight drawback of the heliocentric orbit is the increased telecommunication distance. A High Gain Antenna, affixed to the back end of the observatory, is pointed at Earth to downlink the stored data once or twice a day. This interrupts the observing program, since the telescope is maneuvered for downlink. During observing time the data is collected at regular intervals from the instruments and stored onboard the solid state memory following lossless compression. The science data is collected at a rate to fill up to 4 Gbits of memory within 12 hours. Every 12 hours an opportunity is scheduled to downlink the collected data for 30 minutes at a downlink rate of 2.2 Mbps. The capacity of the solid state memory is 8 Gbits. This allows for one missed pass without permanent loss of data. Concurrent with the downlink, commands can be uplinked at a rate of 2 Kbps. According to the current operations scenario, a weeks worth of sequences is planned and implemented in advance and uplinked once a week. In between scheduled downlinks, uplinks can occur any time via the Omni Low Gain Antenna.

1.2 Warm Launch

SIRTF will be launched at ambient temperature and allowed to radiatively (passively) cool in space within a few weeks after launch. Only the instrument detectors and the cryostat are encased in a vacuum shell, which contains a 360-liter superfluid helium tank that cools the multiple instrument chamber. (MIC) (Figure 2) In this design, the in-orbit parasitic heat load to the cryostat is substantially reduced, leading to a dramatic reduction in the volume of liquid cryogen required. [For comparisons sake, IRAS used

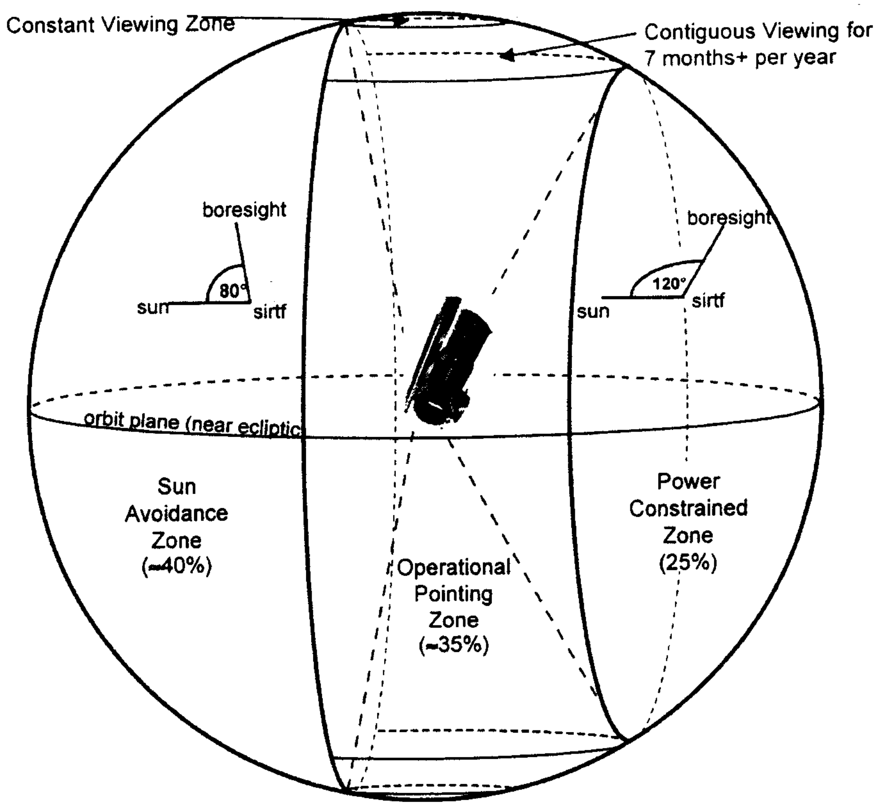

Figure 1: SIRTF's main geometric observing constraints and instantaneous sky visibility.

520 liters over 10 months, and ISO's 30-month mission utilized 2140 liters.] The liquid Helium bath will serve as heat sink and remain at 1°.5 K while the helium boil- off will cool the inner telescope assembly down to 5°.5 K. The outer shell temperature will reach $\sim$ 33°K. The observatory will at all times remain oriented such that the solar panel will shield the CTA from sun light.

2 Some Highlights from the Observatory Design

2.1 Pointing control

The Pointing Control System (PCS) is used to control the orientation of the boresight of the telescope in absolute and relative position. PCS provides the capability for large angle slews between targets as well as short angle

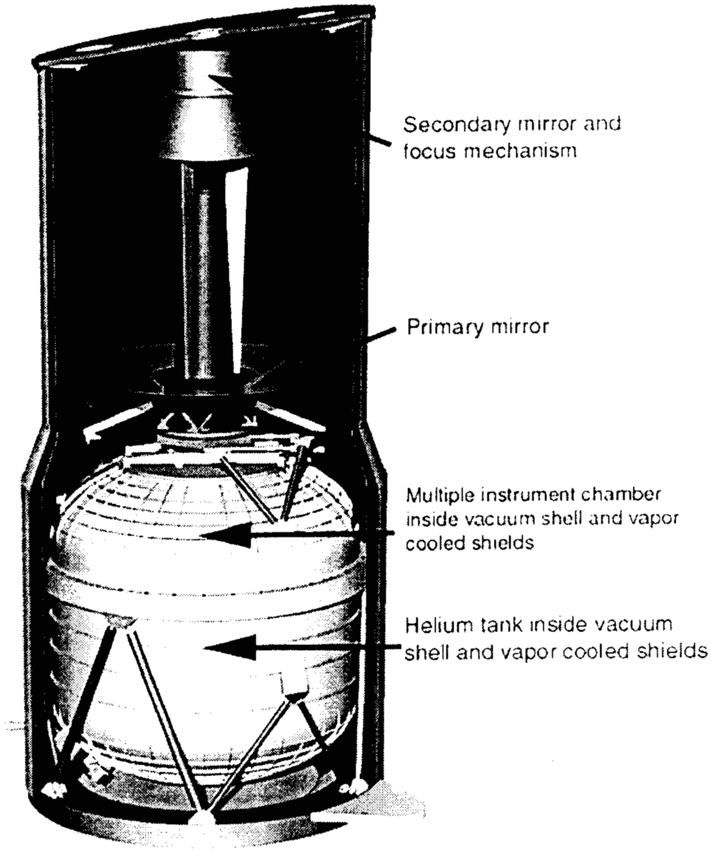

Figure 2: Cutaway view showing the instruments and cryostat in the vacuum shell

slews to place the target into the field of view of the instruments. PCS provides four basic modes that help science observation gathering: inertial pointing, incremental pointing, scan map and tracking.

- During inertial pointing the boresight is kept inertially fixed on a target. This mode is used to perform long integration on faint targets. The stability is $0''.3$ over 200 seconds.
- The incremental pointing mode performs small repositioning of the boresight with an accuracy of $0''.4$. This mode is used to accomplish the super-resolution mode and to move science targets within the focal plane.
- The scan map mode slews the observatory at a constant rate between 2 and $20''$ /s with a scan stability of $0''.7$ and scan rate accuracy of 3% of the commanded rate. This mode is used for efficient mapping of large areas with the MIPS.
- In the tracking mode the observatory boresight follows a precomputed time-tagged target at rates of up to $0''.1$ /s to perform solar system object tracking.

2.2 Instrument overview and capabilities

SIRTF has benefited from a real revolution in infrared detector technology brought about by industry, which served military interests in developing detectors for high-background temperature environments in wavelengths shorter than $30\mu m$. Astronomers have adapted this technology to their needs for low-background and high sensitivity sky observations in the infrared up to $200\mu m$. SIRTF will feature a thousand-fold increase in sensitivity. In addition the size of the arrays has increased many thousands of times as well. The benefit of the high sensitivity and large arrays of detectors is that observations can use short integration time, thus increasing the observatory efficiency.

The MIC is encased in the vacuum shell with the cryostat. The primary and secondary mirrors redirect the incoming light onto the detectors after the aperture door has been opened early in the mission. The instrument cold assembly field of view of the instruments is depicted in the focal plane as shown in Figure 3. SIRTF features three instruments, which provide imaging, photometry and spectroscopy. The focal plane field of view with a diameter of $31'.7$ shows 10 instrument field of views associated with the

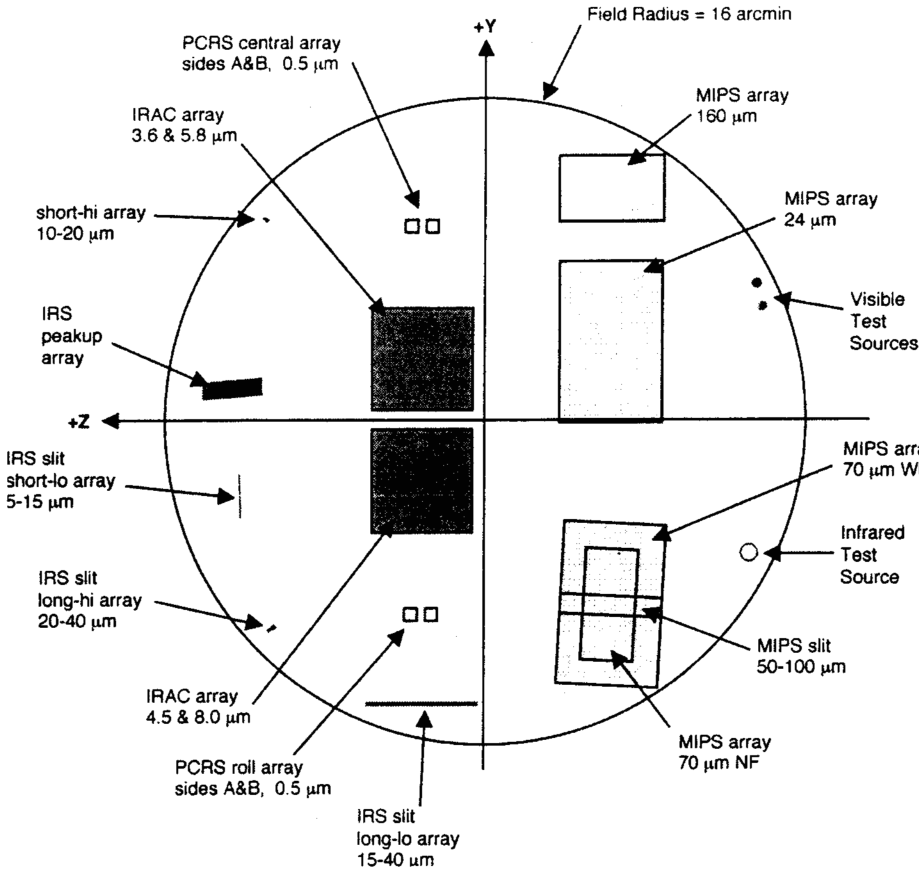

Figure 3: Cold Assemblies Field of View Allocations on the Focal Plane.

three instruments. All instruments view the sky concurrently, but only one instrument is operational at a time. Table 1 summarizes the instrument capabilities.

The **Infrared Array Camera (IRAC)** is a four-channel large field imaging camera, which observes simultaneously at 3.6, 4.5, 5.8, and 8μm. On the focal plane there will be two 5.′12x5.′12 images which view the channels in pairs of 3.6 and 5.8μm in one field of view (FOV) and 4.5 and 8.0μm in the other FOV. The arrays have each a size of 256 by 256 pixels. The two short wave channels use InSb detectors while the two longer wave channels use Si:As IBC detectors. IRAC will address the scientific objectives defined for SIRTF, but will also be used as general-purpose camera for a wide variety of astronomical programs.

The **Multiband Imaging Photometry for SIRTF (MIPS)** is comprised of three detector arrays. The arrays are a 128x128-pixel arsenic-doped silicon (Si:As) for imaging at a wavelength of 24μm, a 32x32 gallium-doped germanium (Ge:Ga) at 70μm, and a 2x20 stressed Ge:Ga array at 160μ. These arrays are optimized for efficient large area surveys and superresolution programs. The 32x32 array also takes very low-resolution spectra from 50-100μm and has a resolution of R $\sim$ 15. MIPS will carry out the following observations: deep field mapping of large areas, photometry of compact sources, super resolution imaging, measurement of spectral energy distributions at low spectral resolution, and total power measurement.

The **InfraRed Spectrograph (IRS)** has four separate modules or cold assemblies. High efficiency grating and echelle spectrographs are used in conjunction with 128x128 pixel Si:As and Si:Sb BIB arrays. The high resolution spectra, Short Hi and Long Hi modules cover 10 to 19.5μm and 19.5 to 38μm respectively with a spectral resolution of 600. The low resolution spectra, Short Lo covers 5 to 15μm while the Long Lo module covers 14 to 40μm with a spectral resolution R = 50. In addition the Short Lo module contains a large field of view, the peak-up array, used to image poorly known sources and locate them precisely for subsequent accurate placement in the spectrograph slits. The IRS is used for diagnostic observations on previously known sources or freshly discovered SIRTF sources.

The **Pointing Calibration and Reference Sensors (PCRS)** located in the MIC are also located in the focal plane. These sensors are used to calibrate any mis-alignment caused to thermo-mechanical effects between the telescope focal plane boresight and the to star tracker boresight.

3 Operations

After an initial 60-day observatory checkout period, the prime mission duration starts and is expected to last up to 5 years. SIRTF will be very efficient due to its instrument sensitivity and innovative mission design. Weekly sequences execute the science observations and calibrations. Roughly every 12 hours observing is going to be interrupted to download the 4 Gbps compressed data to the ground. The instruments are going to be operated one at a time on a rotating basis for a period of 3 to 7 days when the next instrument starts observing.

Science observations are going to be performed by means of seven observing modes. Each observing mode allows the user to unambiguously define the parameters of their observations. These modes are the basic science building blocks for observing with SIRTF. The modes also define unit data

SIRTF Instrument Summary					
Wavelength (microns)	**Array Type**	**Resolving Power**	**Field of View**	**Pixel Sixe (arcsec)**	**Sensitivity (micro-Jy)** 5σ in 500s, inc. confusion
		IRAC: InfraRed Array Camera			
3.6	InSb	5	$5' \times 5'$	1.2	5
4.5	InSb	4	$5' \times 5'$	1.2	5
5.8	Si:As(IBC)	4	$5' \times 5'$	1.2	23
8	Si:As(IBC)	3	$5' \times 5'$	1.2	34
		MIPS:Multiband Imaging Photometer for SIRTF			
24	Si:As(IBC)	4	$5' \times 5'$	2.4	370
70	Ge:Ga	4	$2'.6 \times 2'.6/5' \times 5'$	4.9/9.4	1400
50-95	Ge:Ga	20	$18''.8 \times 4'$	9.4	6500
160	Ge:Gs (stressed)	4	$0'.5 \times 0'.5$ (effective)	15	22.5mJy
		IRS: Infrared Spectrograph			
$\leq$5-15	Si:As(IBC)	50	$3''.6 \times 55''$	1.8	550
15 (Peak-up imaging)	Si:As(IBC)	2	$1' \times 1'.2$	1.8	100
10-20	Si:As(IBC)	600	$4''.8 \times 12.1''$	2.4	$3 \times 10e^{-18} W/m^2$
15-40	Si:As(IBC)	50	$9''.7 \times 145''$	4.8	1500
20-38	Si:As(IBC)	600	$9''.7 \times 24''.2$	4.8	$3 \times 10e^{-18} W/m^2$

Table 1: Overall instrument summary

sets for data processing and archiving.

IRAC has one observing mode for mapping and photometry in all 4 detectors. IRS features two observing modes, the staring mode spectroscopy and spectral mapping. While MIPS has the scan map mode for mapping of large areas on the sky, photometry and super resolution mode, the spectral energy distribution mode and the total power mode. Both science and engineering calibrations are going to be performed using standard parameterized blocks of commands.

The data collected from the downlink will be depacketized and decompressed before being archived within 3-7 days of receipt on the ground. The pipeline processing system will correct the data for instrument and environmental effects. The raw data, the pipeline processed data and the accompanying engineering data will be archived in FITS format, stored on-line and be readily available to users. The legacy teams are likely to produce additional survey datasets, catalogs and atlases, and further processed datasets.

After the primary mission, an extended mission is possible as the telescope gradually warms up to 20°K and the Infrared camera can still be successfully used with its bandwidth of 3.5 and 4.5μm.

4 Primary Science Themes

SIRTF's scientific agenda was re-evaluated and re-defined following the second budget- driven Project re-design in 1994. The SIRTF Science Working Group (SWG) conducted a careful bottoms up re-examination of SIRTF's science objectives at that time. One goal of the study was to identify areas deemed to be of high scientific priority and for which a cooled meter-class telescope with background-limited detectors and multiple instruments could offer substantial improvement over existing capabilities. Another goal, no less important, was to substantially reduce costs associated with every element of SIRTF – the telescope, instruments, spacecraft, ground system, mission operations, and Project management.

With an eye towards cost, and in recognition of the unprecedented sensitivity afforded by the latest infrared detector arrays (Figure 4) physics for which SIRTF could make unique and important contributions. These primary science themes, which received the re- endorsement of the National Research Council's Committee on Astronomy and Astrophysics in 1994, satisfy most of the major scientific questions outlined for the original SIRTF mission in the NRCs Bahcall Report. They are:

1. the search for brown dwarfs and super-planets,
2. the discovery and study of protoplanetary and planetary debris disks,
3. the study of ultraluminous galaxies and active galactic nuclei, and
4. the study of the early and distant Universe.

Apart from being scientifically interesting in their own right, these themes are directly relevant to NASA's *Origins* Program, which seeks to understand the origins of the Universe, galaxies, stars, and planets. While the four primary themes drove the mission redesign, it should be emphasized that SIRTF's powerful capabilities have the potential to address a wide range of other astronomical investigations, including studies of the outer Solar System, the early stages of star formation, and the origin of chemical elements.

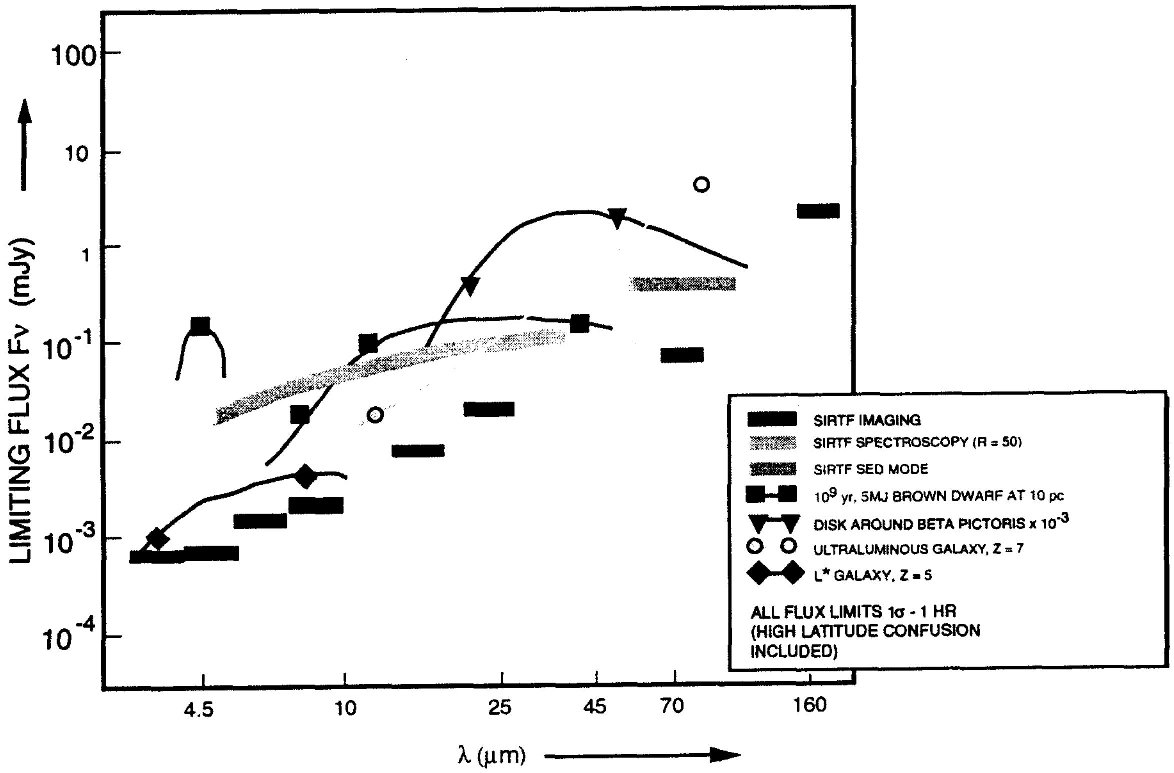

Figure 4: The expected sensitivity of the three instruments as function of wavelength.

Given that one can never underestimate the ingenuity of the community-at-large, potential investigators will be encouraged to propose programs in any scientific area where SIRTF is likely to make significant contributions.

5 Categories of Observing Time

SIRTF's high observational efficiency will yield at least 7500 hours per year of astronomical data. Nearly 80 percent of this observing time will be available to the worldwide user community, with proposals solicited via periodic Calls for Proposals (CPs) issued by the SIRTF Science Center (SSC). It is currently envisioned that there will be consolidated General Observer (GO)/Archival Research CPs issued approximately once per year (assuming a 5-year mission).

One of the innovative aspects of SIRTF is the promotion of very large investigations: the Legacy Science Program. The goal is to establish an opportunity for the community-at- large to propose large investigations that might not normally be approved by time allocation committees. Formally, Legacy Science is distinguished from the canonical GO investigations by these requirements:

1. Large coherent science investigations, not normally reproducible via any reasonable number of smaller Guest Observer investigations;

2. Projects whose scientific data, upon archiving, is of general and lasting importance to the broad community; and

3. Basic calibrated data enter the public domain immediately, thereby enabling timely and effective opportunities for archival research and subsequent follow-on observations.

A likely attribute of Legacy Science is that the projects may utilize many hundreds of hours of SIRTF observing time. Legacy Science projects will be solicited in mid-2000, permitting sufficient time for the selected teams to be established (and funded) prior to launch. These large projects are expected to comprise about half of SIRTFs first year of observing. Since the Legacy Science data will carry no proprietary rights, SIRTF archival data will be available for research purposes within six months of launch the launch date.

To promote full advantage of this extraordinary opportunity, the SIRTF Project and the SIRTF Science Center is in the midst of hosting three annual Conferences/Workshops devoted to scientific areas where SIRTF's capabilities and the Legacy Science opportunity can be productively utilized. The first international conference, *Astrophysics with Infrared Surveys: A Prelude to SIRTF*, was held in June 1998 at Pasadena, California. The conference proceedings have been published by the Astronomical Society of the Pacific (Bicay et al. 1999).

A smaller workshop, *The Solar System and Circumstellar Dust Disks: Prospects for SIRTF*, was held in Dana Point, California in August 1999. The scientific highlights of this workshop appear on the SIRTF Web site.

Finally, a major international scientific conference, Galactic Structure and the Interstellar Medium, will be held in May-June 2000 in Tetons National Park, Wyoming. Details for this conference are available on the SIRTF Web site.

In addition to the Legacy Science program, SIRTF will offer multiple opportunities for the community to propose General Observer and Archival Research investigations. These Calls for Proposals will be issued on an annual basis by the SSC. The CPs and proposal submission will be a completely electronic process, utilizing the SIRTF Web site. Moreover, approved investigators will also retrieve their data electronically from the science archive.

All open observing time on SIRTF, including the Legacy Science Program, is available to worldwide investigators on a competitive peer-review basis. However, NASA cannot provide funding support to approved SIRTF investigators based outside the United States. Given the scope and importance of the Legacy Science Program, foreign proposers will be expected to provide a credible statement of financial support from their home institution and/or sponsoring national agency at the time of the September 2000 proposal submission.

6 Education and Public Outreach

In recognition of NASAs greater emphasis on support for education and public outreach (EPO), SIRTF has defined a vigorous 9-year program to develop educational materials for all students and the general public. SIRTF EPO activities are managed at the SSC, although certain development activities may be contracted out to external groups offering the needed expertise.

The SIRTF EPO Plan (available on the Web site) introduces 13 modules that will be developed during the course of SIRTFs development and operations phases. Much of the intellectual content of these modules will be available to teachers and students via the World Wide Web. The modules are grouped into three primary themes, and are briefly summarized below.

6.1 Theme: The Concept of Temperature

1. More Than the Eye Can See
   The Herschel experiment; contrast between optical and infrared views of the; thermal radiation.

2. The Nature of Light
   Classroom exercises; inverse-square law of radiation; blackbody radiation and temperature.

6.2 Theme: From Photons to Knowledge

1. Decoding Radiation
   Remote sensing of the Universe via photons; radiation as waves/particles; speed of light.

2. To Portray, Visualize and Interpret Data
   Digital images; linear/logarithmic scales; false colors; data manipulation

3. Critical Thinking
   Inductive reasoning; measurements, assumptions and testing.

6.3 Theme: The Scientific Process

1. Posing key questions
   Unresolved issues in astronomy; relevance to infrared astronomy.

2. Capturing Photons
   Astronomy detectors; infrared detectors; the human eye; cryogenics.

3. Better Science Through Engineering
   Innovative ideas; SIRTF's solar orbit and warm-launch architecture.

4. Build a Space Observatory
   Design an observatory; choice of orbit; telemetry; celestial mechanics.

5. Choosing an Astro-Tool
   Selecting observatories and instruments.

6. Stunning Images, Revealing Spectra
   Imaging and spectroscopy.

7. Our Knowledge Evolves
   History of human understanding; key discoveries; major controversies.

8. Lifting the Science Veil
   Public participation in planning observations and analyzing data.

Development of EPO Modules 1 and 2 is underway, and various materials and products associated with these modules will be available to the public by early 2000. Work on Modules 3 through 5 will begin in 2000-2001. It should be emphasized that Module 13 is still being discussed and has not yet been approved by project management. The goal is to develop a multi-year partnering relationship with a world-wide community of teachers and students to provide insight into the scientific process. We are considering concepts that would enable this Internet community to learn about infrared astronomy and the technology inherent in orbiting observatories, and to participate in planning SIRTF observations that would yield scientific data that could then be analyzed. We will inform the community-at-large of the planning details as the concept matures

We are also considering hosting teacher workshops during the summer in Pasadena, in association with other NASA Origins programs based at the Jet propulsion Laboratory. Further details pertaining to these workshops will be made available via the Web, as they become available.

7 Summary

Despite a considerably reduced cost, SIRTF mission design and observatory capabilities allow for a very efficient science program, surpassing past observatories. The vast majority of observing time will be available to the worldwide community, as will be the prompt release of data for archival research. An extensive 9 year Education and Outreach program is in preparation for both national and international students, teachers and the general public.

8 Acknowledgements

This work was supported by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

[1] Bicay, M.D., Beichman, C., Cutri, R.M., and Madore, B.F., eds. Astrophysics With Infrared Surveys: A Prelude to SIRTF. Proceedings of a Science Conference held June 22-24, 1998 in Pasadena, California USA, Publications of the Astronomical Society of the Pacific, vol. 177.